6. SOURCE APPORTIONMENT AND MODELING RESULTS

The Regional Haze Rule requires that the Plan contain information regarding the sources contributing to visibility impairment as well as visibility projections for the 2018 milestone year. To provide the necessary technical and policy tools needed by states and tribes to comply with these requirements, the WRAP has established a Regional Modeling Center (RMC) at the University of California, Riverside with assistance from ENVIRON Corporation and the University of North Carolina. The RMC provides assistance to state and tribal agencies in conducting regional haze analyses over the western United States. This analysis has been performed by operating regional scale, three-dimensional air quality models that simulate the emissions, chemical transformations, and transport of gaseous criteria pollutants and fine particulate matter (PM) and consequent effects on visibility in Class 1 Areas in the western United States. In the RMC analyses, states participated in various forums to help develop a coordinated emissions inventory as discussed in Chapter 3, to evaluate the modeling processes, and to analyze source impacts on regional haze. Detailed information on the WRAP RMC modeling can be found in Appendix E.

6.1 Description of Source Apportionment Methods

A variety of modeling and data analysis methods can be used to evaluate the role of different source types in contributing to visibility at a given receptor site. One method, the weighted emissions potential analysis, was developed as a screening tool to decide which source regions have the potential to contribute to haze formation at Class 1 Areas, based on annual emissions inventories, baseline period wind patterns, and source to Class 1 Area distances. Although the weighted emissions potential analyses used a slightly different inventory than the modeling used to estimate future concentrations, it is still a good indicator of the sources contributing to haze.

Another method of source apportionment is to implement a mass-tracking algorithm in an air quality model to explicitly track for a given emissions source, the chemical transformations, transport, and removal of the PM that was formed from that source. This algorithm, the PM Source Apportionment Technology (PSAT), was implemented in the Comprehensive Air Quality Model with extensions (CAMx) and used for the WRAP modeling analysis. PSAT performs source apportionment based on user-defined source groups. A source group is the combination of a geographic source region and an emissions source category. PSAT was performed for organic carbon, sulfate and nitrate. The different source categories evaluated include point sources, area sources, biogenics, off-shore emissions, natural and anthropogenic fires, on- and off-road mobile sources, road dust, fugitive dust, and wind blown dust.
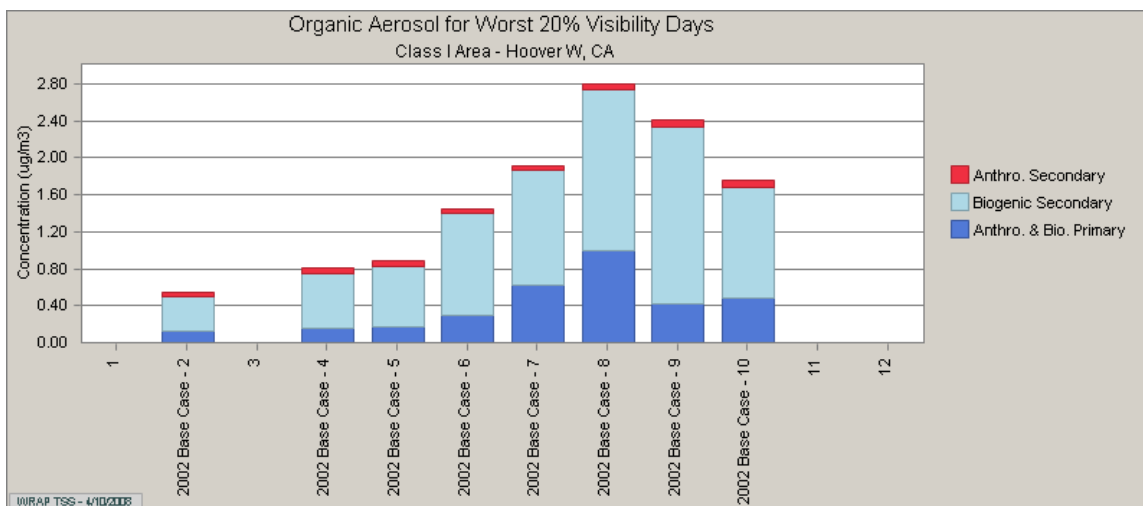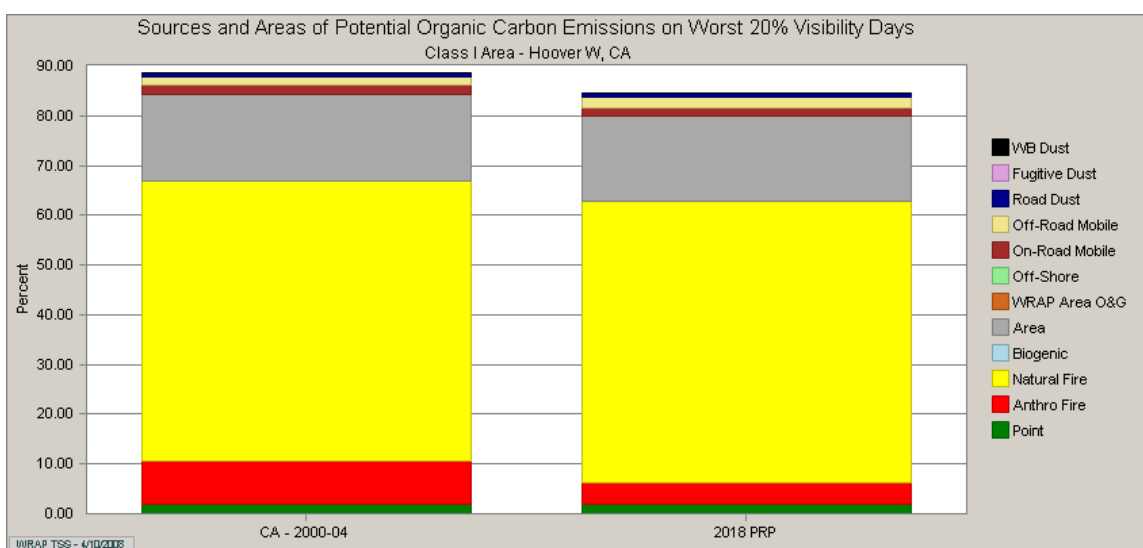
6.2 <u>Source Apportionment Results</u>

Examples of the results of these source apportionment methods are provided in this section in order to highlight how these tools can be used to identify the key source contributions to haze at California's Class 1 Areas. Results are shown for organic carbon, nitrate, and sulfate, the three drivers of haze in California. These examples illustrate three key groupings of source contributions: 1) anthropogenic sources within the WRAP region, 2) natural sources, and 3) sources, both anthropogenic and natural, from outside the WRAP region. More detailed information on source attribution for each individual Class 1 Area can be found in Appendix B.

6.2.1 Organic Carbon Source Apportionment

As described in Chapter 2, organic carbon is a key driver of haze at many Class 1 Areas. Figure 6-1 shows source apportionment results for organic carbon at the Hoover Class 1 Area on the 20 percent worst days. The plot shows the amount of organic carbon that is derived from secondary organic aerosols from biogenic sources, secondary organic aerosols from anthropogenic emissions, and organic carbon that is directly emitted from both biogenic and anthropogenic sources. The secondary biogenic contributions to haze are the result of VOC emissions from plants, which react in the atmosphere to form organic aerosols. Biogenic contributions are significant throughout the year, but increase substantially during the summer months when plants are in their most active growth phase. The contribution from anthropogenic secondary organic aerosols (i.e. from anthropogenic VOC emissions) is very small. The remaining organic carbon comes from directly emitted sources, which also increase during the summer.

Figure 6-2 shows the results of the weighted emissions potential analysis for sources of directly emitted organic carbon at Hoover on the 20 percent worst days in 2002 as compared to 2018. The weighted emissions potential analysis shows that natural fire (wildfires) is the largest contributor, representing approximately 50 percent of the directly emitted organic carbon. This contribution is expected to remain constant in 2018. A large contribution from natural fire is seen at many Class 1 Areas in Northern California and the Sierras, with some areas such as Dome Lands indicating that almost 90 percent of the directly emitted organic carbon can be attributed to natural fire.

Figure 6-1 Organic Aerosol Source Attribution

**Figure 6-2 Sources of Organic Carbon on Worst 20 Percent Haze Days**

6.2.2 Nitrate (NOx) Source Apportionment

Figures 6-3 and 6-4 illustrate the results of the nitrate PSAT analysis for the San Gabriel Wilderness Area on the 20 percent worst days. In contrast to the previous organic carbon example, the bulk of nitrate contributions at San Gabriel were found to come from anthropogenic sources, with roughly 75 percent of the nitrate from sources within the WRAP region. Of this, the largest contributions were from on- and off-road mobile source emissions in California. The figures also highlight the substantial future visibility improvement that will result from mobile source sector emission reductions. Similar findings regarding the predominance of California mobile sources were found for nitrate at the majority of other Class 1 Areas.

Figure 6-3 Sources of Nitrogen Oxides on Worst 20 Percent Haze Days
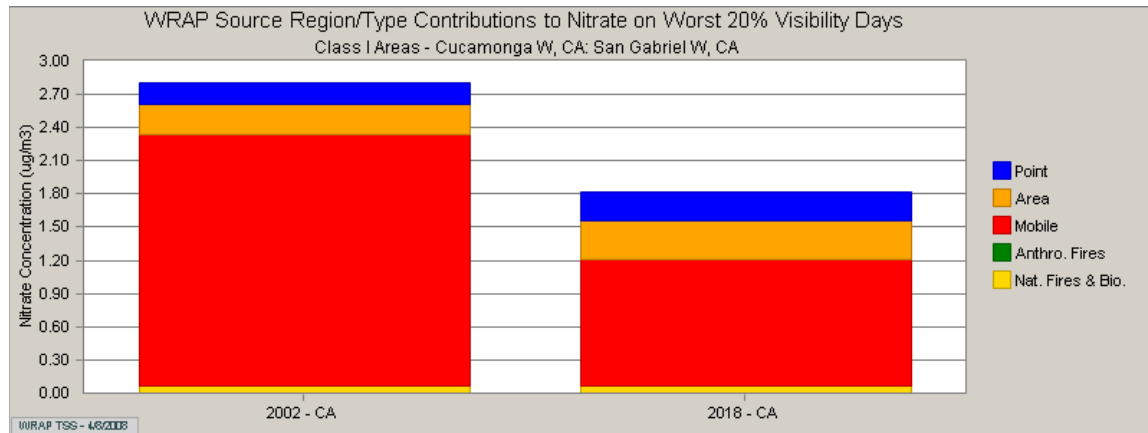
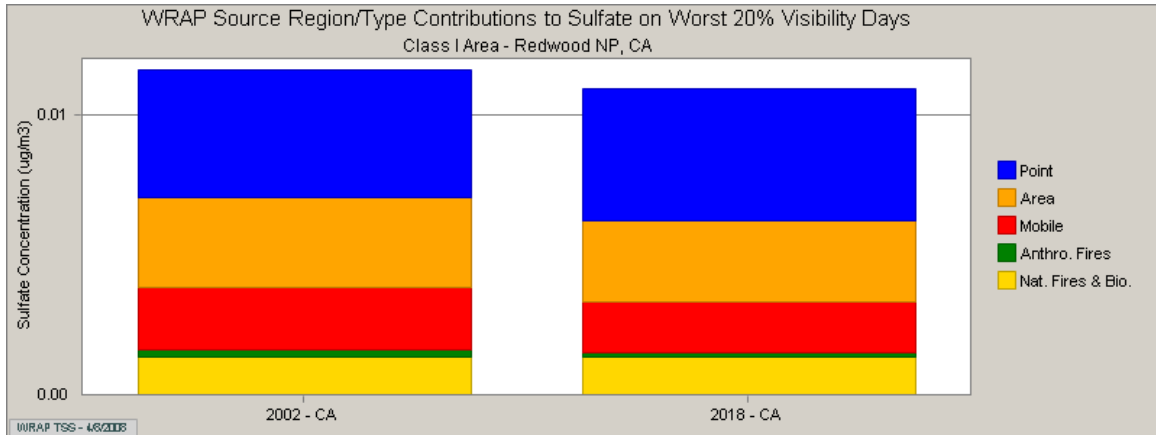**Figure 6-4 Source Region Origin of Nitrate on Worst 20 Percent Haze Days**
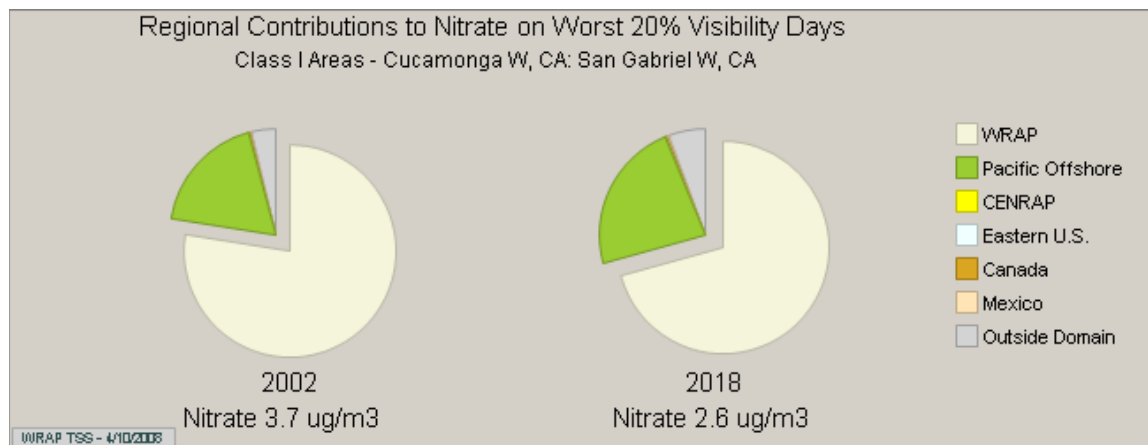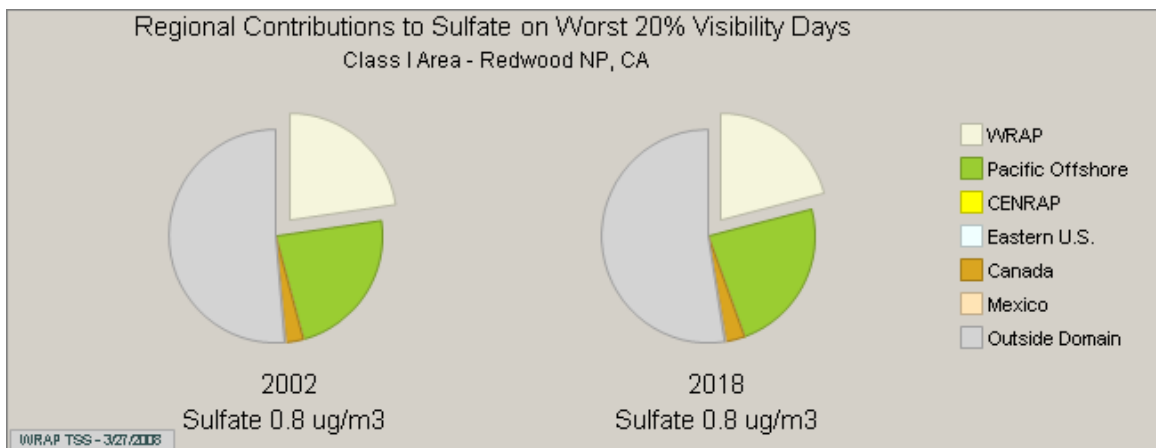

6.2.3 Sulfate Source Apportionment

Figure 6-5 shows the results of sulfate PSAT analysis for Redwoods National Park on the 20 percent worst days. Point and area sources represent the largest category of California emissions for sulfate, however, California's aggregate contribution is less than 2 percent to the modeled sulfate contributions at Redwoods. On the coast, sulfur oxide sources include natural emissions from marine organisms, as well as large contributions from shipping in the Pacific Off-Shore region. Figure 6-6 provides an example of the impact of different source regions at the Redwoods Class 1 Area based on the PSAT analysis. This analysis illustrates that not only do the emissions that are quantified in the Pacific Offshore region contribute significantly, but that emissions outside the WRAP modeling domain contribute approximately half of the sulfate at this Class 1 Area.

Similar impacts from non-WRAP source regions were seen at California's other Coastal and Southern California sub-region sites.

Figure 6-5 Sources of Sulfur Oxides on Worst 20 Percent Haze Days

Figure 6-6 Source Region Origin of Sulfate on Worst 20 Percent Haze Days

6.2.4 Summary of California Source Apportionment

Using the weighted emissions potential analyses, estimates for the 20 percent worst haze days based on baseline conditions were made for each Class 1 Area of the contribution from directly emitted organic carbon emissions that are derived from California anthropogenic emission sources. California anthropogenic, directly emitted, organic carbon appears to contribute approximately half or less of the organic carbon in most areas except Point Reyes National Seashore (67 percent) and Pinnacles Wilderness Area (73 percent). Class 1 Areas in Southern California show less than 40 percent contributions from the anthropogenic, directly emitted, organic carbon sources. As explained in earlier sections, much of the directly emitted organic carbon in

California comes from wildfires. In addition, source apportionment modeling found that the majority of secondary organic carbon is derived from biogenic emission sources.

PSAT modeling was also conducted to provide estimates of the source region/categories contributing to nitrate and sulfate at each Class 1 Area. For nitrate, California anthropogenic NOx sources contribute 50 percent or more of the nitrate in all California Class 1 Areas with the exception of Redwoods National Park (7 percent). In contrast, the California anthropogenic sulfate contribution ranges from 1 to 35 percent. Class 1 Areas in California, especially the Coastal sub-region and in Southern California see larger impacts from off-shore shipping. Class 1 Areas in Southern California show slightly higher contributions from California anthropogenic sulfate (22 percent to 35 percent) than other Class 1 Areas, reflecting the proximity to point sources such as refineries as well as port-related activities. Using the information from the California anthropogenic emission sources in combination with the examples provided in Figures 6-1 through 6-6, the three primary drivers of haze in California will continue to come from natural sources for carbon, mobile sources for nitrate, and off-shore and non-WRAP region sources for sulfate. As stated in Chapter 4, California's 2018 Progress Strategy focuses on achieving significant reductions from sources within our jurisdiction, particularly mobile sources.

6.3   Transported Sources that Impact Baseline Visibility

As illustrated in the previous section, while sources within California have an influence on visibility at California Class 1 Areas, sources outside of California also cause an impact. The varied and complex terrain of California, coupled with complex meteorology allow for the transport of emission sources to Class 1 Areas from areas as close as neighboring states, Mexico, and the Pacific Ocean, to as far away as Asia. The following sections provide brief descriptions of the source regions outside of California that also cause visibility impacts in California's Class 1 Areas.

6.3.1 Mexico

Mexican emissions, particularly SOx, can be significant contributors to decreased visibility. The Class 1 Areas in the Salton Sea and the San Diego Air Basins are particularly influenced by transport from Mexico. California is strongly involved in collaborative efforts to complete emissions inventories and conduct pollutant monitoring to better characterize these impacts.

6.3.2 Asian dust

Asian dust has been seen in North America for a few very large events, most notably in April 1998 and again in April 2001. Some of this dust is natural but it is often accompanied by biomass smoke, agricultural dust, motor vehicle and industrial emissions. Asian aerosols can be a major component of PM in otherwise "clean" rural sites, but control of this source is difficult. Figure 6-7 shows the 2001 Asian dust storm and its affects on California monitors. Figure 6-8 shows a satellite photo of an Asian dust cloud.

Figure 6-7 Asian Dust Storm affect on CA monitors
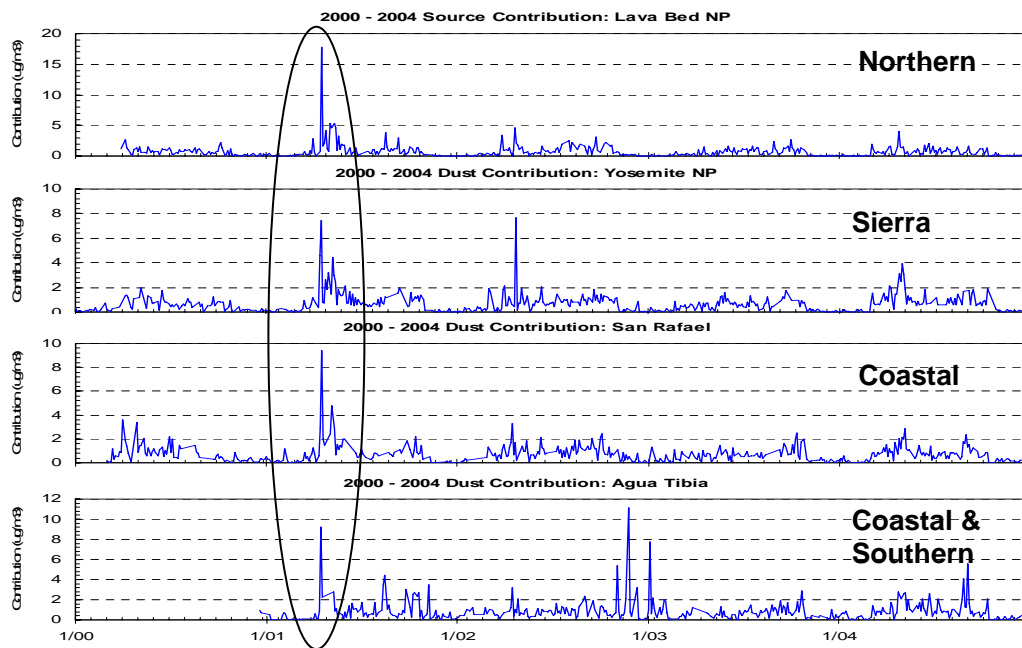
Figure 6-8 Asian Dust Storm traveling over to North America
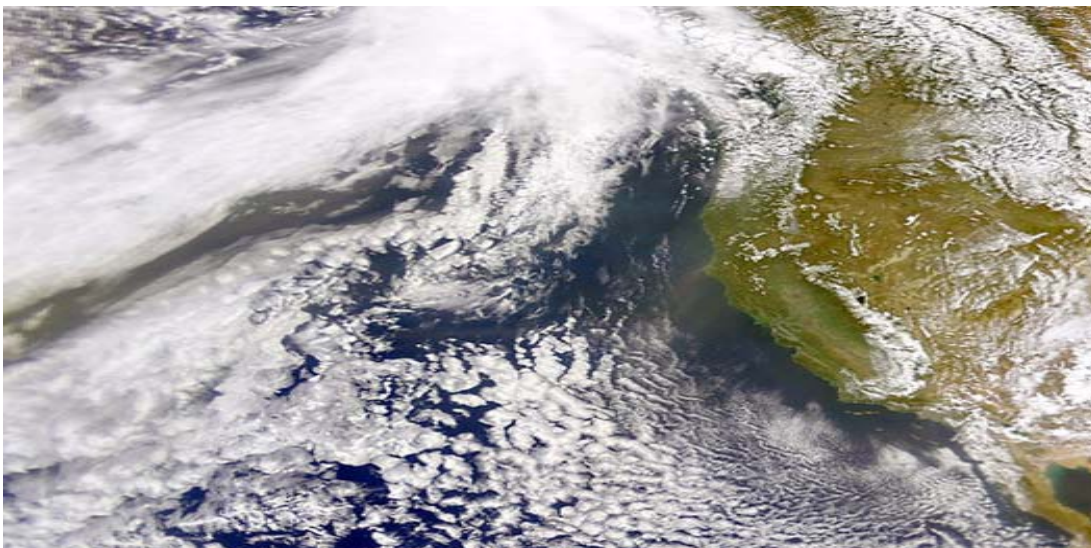
6.3.3 Pacific Ocean, shipping emissions

Emissions from ocean-going vessels are a substantial contributor to sulfate visibility impairment at many of California's Class 1 Areas near the coast. Significant growth in shipping activity is expected in the near future. Ships have little or no emissions controls and tend to run on high emitting bunker fuel. The WRAP Pacific Offshore category looks at the combined offshore emissions from California, Washington, and Oregon. California control efforts for the near-shore portion of these emissions within our jurisdiction are described in Chapter 4, however, additional national and international efforts are needed to reduce the emissions from ships in transit further offshore.

6.3.4 Neighboring States

With mountains in the east and north, the ocean to the west, and prevailing weather patterns that move from west to east, emissions from neighboring states are not expected to significantly impact California, except for smoke from large wildfires. The western states are working in partnership through the WRAP to provide for coordinated haze planning in the West.

6.4   <u>CMAQ Modeling Results for 2018</u>

The previous sections provided an assessment of the sources contributing to haze. The Regional Haze Rule also requires an estimate of the effectiveness of California's 2018 Progress Strategy in improving visibility to be used in setting reasonable progress goals. In order to understand how emission source projections impact visibility in the future, the RMC used the Community Multi-scale Air Quality (CMAQ) model to simulate expected visibility levels in 2018 for the WRAP region. The CMAQ model has been designed to approach air quality as a whole by including state-of-the-science capabilities for modeling multiple air quality issues, including visibility degradation, fine particles, ozone, toxics, and acid deposition. In this way, CMAQ combines the capabilities to enable a community modeling practice. CMAQ is also designed to have multi-scale capabilities so that it can be used for urban and regional scale model simulations. The number and size of grid cells and the number and thicknesses of layers are defined by the user, based in part on the size of the modeling domain to be used for each modeling project. CMAQ offers a variety of choices in the numerical algorithms for treating many of these processes, and it is designed so that new algorithms can be included in the model.

CMAQ was used to project visibility levels from the mandated five-year (2000-2004) baseline period to 2018, the end of the first progress period, for both the 20 percent worst and 20 percent best days. This reflects the WRAP Plan02c and 2018b emissions scenarios. The visibility levels are estimated using baseline meteorological conditions and baseline and future emission inventories. Since it is difficult to replicate actual values, the model is used in a relative sense

to evaluate the impact of emission changes. This relative change is called the Relative Response Factor (RRF), which is defined as the ratio of the future-year modeling results to the current-year modeling results. The calculated RRFs are then applied to the baseline observed visibility conditions to project 2018 observed visibility.

Table 6-1 shows the 2018 modeling results for the 20 percent worst and 20 percent best days. It is based on the monthly weighted RRFs comparing the 2000-04 baseline emissions to 2018 emissions. California selected the monthly weighted RRFs since they more accurately reflected the seasonality of the visibility problem. As shown in Table 6-1, the 2018 modeled projections for the 20 percent worst visibility days in all Class 1 Areas in California make progress towards natural conditions despite only having control of up to 50 percent of the problem. The 2018 modeled projections for the 20 percent best visibility days in all Class 1 Areas in California also show improving visibility.

The degree of improvement is dependent upon the contributions in each area from anthropogenic versus natural emission sources, as well as from sources outside of California. For example, in San Gorgonio, a wilderness area that is just downwind of the South Coast Air Basin, the improvement in visibility is nearly eight times larger than that achieved at Desolation, a wilderness area near Lake Tahoe. Because visibility is largely due to anthropogenic emissions in the upwind urban areas of the South Coast, the comprehensive control programs of ARB and the South Coast Air Quality Management District to attain the federal ozone and particulate matter standards will result in significant improvements in visibility at San Gorgonio. In contrast, analysis of the nature of the visibility problem at Desolation has found that wildfires as well as natural emissions from plants are a large portion of visibility impairment in the area. Therefore controls on anthropogenic emissions have a much more limited impact.

Table 6-1 Visibility Progress Summary (deciviews, Haze Algorithm II)

Class 1 Area(s) *WA=Wilderness Area* *NP=National Park* *NM=National Monument* *NS=National Seashore*	20% Worst Haze Days Baseline (2000-04)	20% Worst Haze Days Modeled Projection for 2018	20% Worst Haze Days Natural Conditions Target (2064)	20% Best Visibility Days Baseline (2000-04)	20% Best Haze Days Modeled Projection for 2018
NORTHERN CALIFORNIA					
Lava Beds NP South Warner WA	15.1	14.4	7.9	3.2	3.0
Lassen Volcanic NP Caribou WA Thousand Lakes WA	14.2	13.3	7.3	2.7	2.5
Marble Mountain WA Yolla Bolly-Middle Eel WA	17.4	16.4	7.9	3.4	3.2
SIERRA CALIFORNIA					
Desolation WA Mokelumne WA	12.6	12.3	6.1	2.5	2.5
Hoover WA	12.9	12.5	7.7	1.4	1.3
Yosemite NP Emigrant WA	17.6	16.7	7.6	3.4	3.2
Ansel Adams WA Kaiser WA John Muir WA	15.5	14.9	7.1	2.3	2.1
Sequoia NP Kings Canyon NP	25.4	22.7	7.7	8.8	8.1
Dome Lands WA	19.4	18.1	7.5	5.1	4.7
SOUTHERN CALIFORNIA					
San Gabriel WA Cucamonga WA	19.9	17.4	7.0	4.8	4.1
San Gorgonio WA San Jacinto WA	22.2	19.9	7.3	5.4	5.0
Joshua Tree WA	19.6	17.9	7.2	6.1	5.7
Agua Tibia WA	23.5	21.6	7.6	9.6	8.9
COASTAL CALIFORNIA					
Redwood NP	18.5	17.8	13.9	6.1	5.8
Point Reyes NS	22.8	21.3	15.8	10.5	10.1
Pinnacles WA Ventana WA	18.5	16.7	8.0	8.9	8.1
San Rafael WA	18.8	17.3	7.6	6.4	5.8

TSS Date: 11/12/2008

To provide insight into the visibility improvement that will result from NOx (primarily mobile source sector) emission reductions, Table 6-2 shows 2018 modeled visibility progress from nitrate reductions. The 2018 nitrate modeled projections for the 20 percent worst visibility days in all Class 1 Areas in California make tremendous progress. Between the baseline period and 2018, modeled nitrate is reduced from 21 percent to 56 percent at Class 1 Areas in California. Tables 6-3 and 6-4 show 2018 modeled visibility progress from sulfate and organic carbon (OC) reductions, respectively. Even though the

sulfate and OC reductions do not make as much progress as nitrate, the 2018 modeled projections for 20 percent worst visibility days in all Class 1 Areas in California are reduced up to 5 percent for sulfate and from 4 to 22 percent for OC. Sulfate and OC show less progress due to the impacts of uncontrollable sources such as shipping/offshore and biogenic/wildfire emissions.

Table 6-2   Modeled visibility progress from nitrate reduction with California's 2018 Progress Strategy

Class 1 Area(s) *WA=Wilderness Area* *NP=National Park* *NM=National Monument* *NS=National Seashore*	20% Worst Haze Days Baseline (2000-04) (Mm-1)	20% Worst Haze Days Modeled Projection for 2018 (Mm-1)	Nitrate Visibility Progress towards 2018 (%)
NORTHERN CALIFORNIA			
Lava Beds NP South Warner WA	3.5	2.4	31
Lassen Volcanic NP Caribou WA Thousand Lakes WA	3.7	2.1	43
Marble Mountain WA Yolla Bolly-Middle Eel WA	6.1	3.6	41
SIERRA CALIFORNIA			
Desolation WA Mokelumne WA	2.4	1.7	29
Hoover WA	1.6	1.2	25
Yosemite NP Emigrant WA	8.1	5.3	35
Ansel Adams WA Kaiser WA John Muir WA	7.0	5.5	21
Sequoia NP Kings Canyon NP	60.7	30.4	50
Dome Lands WA	16.0	8.5	47
SOUTHERN CALIFORNIA			
San Gabriel WA Cucamonga WA	27.7	16.1	42
San Gorgonio WA San Jacinto WA	44.9	28.8	36
Joshua Tree WA	27.3	17.8	35
Agua Tibia WA	29.9	16.3	45
COASTAL CALIFORNIA			
Redwood NP	6.0	4.2	30
Point Reyes NS	38.4	21.2	45
Pinnacles WA Ventana WA	17.1	9.1	47
San Rafael WA	12.6	5.6	56

TSS Date: 11/12/2008

Table 6-3   Modeled visibility progress from sulfate reduction with California's 2018 Progress Strategy

Class 1 Area(s) *WA=Wilderness Area* *NP=National Park* *NM=National Monument* *NS=National Seashore*	20% Worst Haze Days Baseline (2000-04) (Mm-1)	20% Worst Haze Days Modeled Projection for 2018 (Mm-1)	Sulfate Visibility Progress towards 2018 (%)
NORTHERN CALIFORNIA			
Lava Beds NP South Warner WA	6.8	6.6	3
Lassen Volcanic NP Caribou WA Thousand Lakes WA	6.8	6.6	3
Marble Mountain WA Yolla Bolly-Middle Eel WA	8.4	8.1	4
SIERRA CALIFORNIA			
Desolation WA Mokelumne WA	5.1	5.1	0
Hoover WA	5.0	4.9	2
Yosemite NP Emigrant WA	7.9	7.7	3
Ansel Adams WA Kaiser WA John Muir WA	7.6	7.5	1
Sequoia NP Kings Canyon NP	16.5	16.2	2
Dome Lands WA	12.0	11.8	2
SOUTHERN CALIFORNIA			
San Gabriel WA Cucamonga WA	12.3	11.7	5
San Gorgonio WA San Jacinto WA	13.2	12.8	3
Joshua Tree WA	12.3	11.8	4
Agua Tibia WA	31.8	30.2	5
COASTAL CALIFORNIA			
Redwood NP	14.9	14.2	5
Point Reyes NS	14.1	13.8	2
Pinnacles WA Ventana WA	13.9	13.6	2
San Rafael WA	20.4	19.9	2

TSS Date: 11/12/2008

Table 6-4   Modeled visibility progress from organic carbon reduction with California's 2018 Progress Strategy

Class 1 Area(s) WA=Wilderness Area NP=National Park NM=National Monument NS=National Seashore	20% Worst Haze Days Baseline (2000-04) (Mm-1)	20% Worst Haze Days Modeled Projection for 2018 (Mm-1)	OC Visibility Progress towards 2018 (%)
NORTHERN CALIFORNIA			
Lava Beds NP South Warner WA	22.0	20.9	5
Lassen Volcanic NP Caribou WA Thousand Lakes WA	17.2	15.6	9
Marble Mountain WA Yolla Bolly-Middle Eel WA	35.3	32.5	8
SIERRA CALIFORNIA			
Desolation WA Mokelumne WA	14.1	13.3	6
Hoover WA	15.4	14.5	6
Yosemite NP Emigrant WA	29.0	26.4	9
Ansel Adams WA Kaiser WA John Muir WA	16.8	15.7	7
Sequoia NP Kings Canyon NP	32.4	30.2	7
Dome Lands WA	17.1	16.2	5
SOUTHERN CALIFORNIA			
San Gabriel WA Cucamonga WA	15.3	11.9	22
San Gorgonio WA San Jacinto WA	14.0	12.6	10
Joshua Tree WA	10.3	9.5	8
Agua Tibia WA	17.6	16.5	6
COASTAL CALIFORNIA			
Redwood NP	8.0	7.7	4
Point Reyes NS	12.1	11.5	5
Pinnacles WA Ventana WA	13.2	12.1	8
San Rafael WA	12.4	11.2	10

TSS Date: 11/12/2008

In summary, modeling and source apportionment results show that all 29 California Class 1 Areas make progress towards improving visibility in 2018 and that California's 2018 Progress Strategy is effective at reducing emission sources under State control.

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